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FMS 환경하의 효율적인 버퍼관리에 관한 연구

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An Efficient Buffer Management in a Multi-Cell Flexible Manufacturing Systems

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This research is concerned with buffer management in a multi-cell FMS(Flexible Manufacturing System) with an AGVS(Automated Guided Vehicle System). To reduce blocking and starving caused by breakdowns, variability in process times, and diversity of part routing, buffer is needed. Due to the high per unit buffer cost, which primarily consists of floor space and equipment costs, the total capacity of buffers in an FMS is very limited. Therefore, proper buffer management can provide a high system efficiency. This paper presents a buffer management model for a multi-cell FMS with an AGVS and a simulation study to compare the proposed model to a conventional buffer management model in a job shop FMS.

1. Introduction

FMSs(Flexible Manufacturing Systems) have provided the necessary efficiencies normally associated with higher volume transfer lines, while retaining much of the flexibility of manually operated job shops. An FMS consists of CNC(Computer Numerically Controlled) machines organized in cells, a MHS(material handling system), and a computer control system for integrating the functions of CNC machines and the MHS.

Buffers in a multi-cell FMS can be broadly classified into three types: machine buffers, cell buffers. and system buffers. A machine buffer is attached to a machine and is accessible only by parts that visit that machine. A cell buffer is accessible by parts visiting that cell, while a system buffer is accessible to any part in the system. Some multi-cell FMSs use all three buffer types while others use one or two buffer types. Figure 1 depicts the hierarchy of the three buffer types based on the location of the buffer.

Access to buffer spaces may be sequential or random. In a sequentially-accessible buffer, only the location at the ends may be accessed, whereas in a randomly-accessible buffer, any location in the buffer may be accessed. In an automated job shop it is very plausible that some parts require backtracking, that is, some parts must revisit a process that they have already visited. Furthermore, since parts have different processing steps, the flow of parts might not be unidirectional. These conflicts in the part's flow generally increase system congestion and affect the system throughput. A combination of backtracking, non-unidirectional flow, and limited buffer space promote deadlock conditions in an FMS.

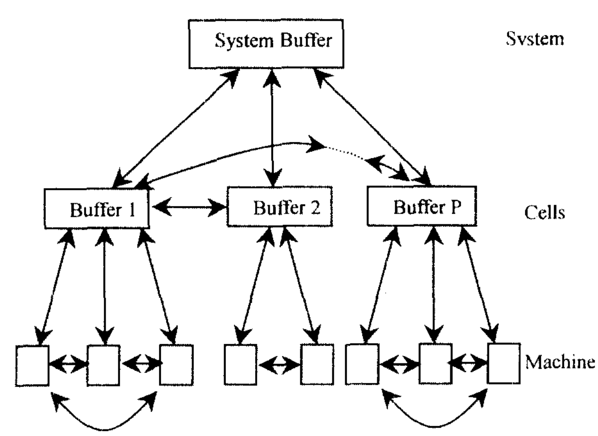

Figure 1. A hierarchy of three buffer types

The total capacity of buffers in an FMS is very limited. This is due to the high per unit buffer cost that primarily consists of floor space and equipment costs. Therefore, in order to increase the system throughput and to reduce the deadlock possibility, a proper buffer management strategy must be considered before contemplating any increase in the buffer capacities. When devising a buffer management strategy for an FMS with AGVs, the unique characteristics of buffering in such a system must be considered. In this paper we discuss the problem of buffer management in an FMS with AGVs, and propose a buffer management strategy.

2. REVIEW OF LITERATURE

A large number of parts in the system cause excessive congestion and traffic on the shop floor and consequently increase the possibility of deadlock[10, 13]. One approach to keep congestion and blocking is to control the flow of unit loads into the system. Garetti et. al.[5] carried out a simulation study for a static dedicated FMS by examining machine dispatching rules versus input control rules with utilization and mean flow time as the criteria. The results indicate that as the size of the system buffer increases, the utilization value of the system rises, and the difference between the various input control rules diminishes. Similar results can be found in the paper by Sabuncuoglu and Hommertzheim[9]. They conclude that at a very low buffer capacity, scheduling of MHS and input control may become more critical than dispatching machines.

Buzacott and Shanthikumar[2] showed analytically that an FMS with only a system buffer is superior to a system with only individual cell buffers. Kamoun and Kleinrock[6] proposed a scheme that controls the usage of a shared buffer(system buffer) for a computer network node environment.

Sabuncuoglu and Hommertzheim[10] investigated the effects of the number of jobs allowed into an FMS with AGVs and examined different machine and AGV scheduling rules by comparing the mean flow time performance.

In an FMS with an AGVS, one of the important problems is the system deadlock caused by the limited buffer and the lack of mechanism to prevent it[4]. The deadlock problem in FMS environments is addressed by several authors. The approaches taken in the FMS research to solve deadlock problems include Petri-net[1, 3], Graph theory[12] and Queueing network[7]. Most of the above approaches are implemented in real-time scheduling and control. Complexity and performance of each model is problem specific.

An increasing number of papers concerned with FMS scheduling and control continues to appear in the literature. However, research efforts to investigate the effect of different buffer management policies on FMS performance are very scarce and limited[11].

3. VIRTUAL SYSTEM BUFFER

As stated previously, in general, three buffer types could exist in a multi-cell FMS. They are machine, cell and system buffers. At the machine and cell levels, buffers may be segregated into input and output buffers.

Segregated buffers can be accessed sequentially or randomly. A sequentially-accessible buffer is generally less expensive to build and easier to control than a randomly-accessible buffer. The choice of priority rule for selecting a part from a sequentially-accessible buffer is limited to the FCFS(First Come First Serve) rule or the LCFS(Last Come First Serve) rule which makes a sequentially-accessible buffer less flexible than a randomly-accessible buffer. However, a variety of priority rules can be used with a randomly-accessible buffer. Thus, by using a randomly-accessible buffer, the full flexibility potential of an FMS can be realized.

A non-segregated input and output buffer creates a common input/output(I/O) buffer for use by both incoming and outgoing parts. Preferably an I/O buffer should be randomly-accessible. Because managing a sequentially-accessible I/O buffer creates unavoidable machine starvation, and nullifies the advantages gained from non-segregation of input and output buffers. The primary advantage of a randomly-accessible I/O buffer over segregated buffers is reduction of machine and part blockings.

To reduce deadlocks as well as blocking, some parts should be sent to the system buffer from cell buffers. Also to reduce starving, some parts in the system buffer should be sent to corresponding cell buffers. Figure 2 depicts these part's movement between system buffer and cell buffer.

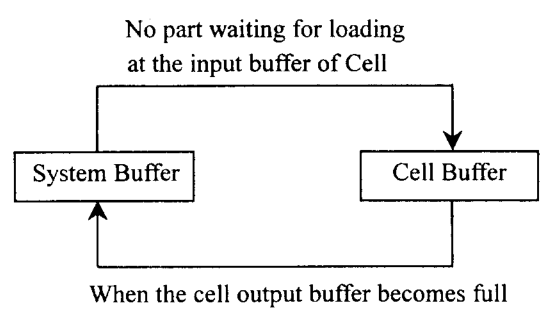

Figure 2. A movement of parts between system buffer and cell buffer

Conventionally, only the system buffer receives parts that are requested to leave their current cells while their ultimate destinations have no free spaces. However, if the system buffer has no free spaces either, the parts have to wait at their current locations and will consequently block other parts. For the system with a small system buffer, one alternative is to send those parts temporarily to other cell buffers that have large available spaces and are close to the ultimate destinations of the parts. The most difficult obstacle to implement this idea is that to be efficient, cell buffers should be randomly-accessible and capable of loading and unloading parts to AGVs, and the system controller should have the information on the status of the each buffer. Indeed, it is difficult to find a system that uses this idea in conventional job shop environments. Technically, the concept of FMSs with AGVs can accommodate this scenario because in general FMSs with AGVs and common I/O cell buffers do provide the randomly-accessible cell buffers, such as a carousel, and also provide the integrated computer system. However, there has been no accepted control model to implement this idea with FMSs in combination with AGVs. Here, a virtual system buffer is defined as the portion of a cell buffer that is temporarily shared with other cells.

4. SIMULATION OF VIRTUAL SYSTEM BUFFER STRATEGY

A virtual system buffer management model is proposed for minimizing the required size of the system buffer without compromising throughput. To investigate the behavior of this model, the model is tested through a computer simulation on a hypothetical system. The results are then compared with that of a conventional model in which each cell has an input buffer and an output buffer.

4.1 Conventional Buffer Model

The term conventional approach for buffer management, as used here, applies to the approach that physically divides each cell I/O buffer into one input buffer and one output buffer. And the part flow from the system buffer to the cell input buffer selected is similar to the virtual system buffer model where parts in the system buffer are pulled by $Cell_i$ whenever there is no part waiting for loading at the input buffer of $Cell_i$. Also a part in a cell output buffer is pushed to the system buffer when the cell output buffer becomes full.

4.2 Virtual System Buffer Model

The proposed model is developed for a multi-cell FMS where each cell has a randomly-accessible cell I/O buffer.

Three sequential milestones are fundamental to part movements between buffers. They are: arrival milestone which occurs when a part arrives at a cell I/O buffer, reservation milestone which occurs when a part reserves its next destination place and departure milestone which occurs when a part departs from a cell I/O buffer. Between these three milestones, a part may have to wait until certain conditions are met such as the availability of its destination place and/or an AGV. The proposed model has three modules detailing action/events surrounding each milestone: (a) reservation request for a place in a cell I/O buffer, (b) part arrival at a cell I/O buffer, and (c) departure of a part from a cell I/O buffer. Each module contains actions that should be taken at each corresponding milestone.

The first module, reservation request for a place in a cell I/O buffer, this module is invoked whenever a part tries to reserve a place at a cell I/O buffer.

Under this model, at least two places in I/O_i must be used only for $Cell_i$. One of them is always reserved for the outgoing parts from resources within $Cell_i$, whereas the other place can be used by an incoming part from other cells. The purpose of this strategy is to reduce the blockage of incoming parts. For instance, if outgoing parts occupy the total capacity of a cell I/O buffer, incoming parts cannot arrive even though all machines are idle. By holding outgoing parts at machines, such instances can be prevented.

After a part arrives at a cell I/O buffer, the second module, part arrival at a cell I/O buffer, is invoked. In this module, two actions are taken: switching a blocked outgoing part with an incoming part as mentioned above and sending a part to a virtual system buffer or a system buffer if the cell I/O buffer is congested.

The third module, departure of a part from a cell I/O buffer, is invoked right after a part leaves from an I/O buffer. In this module, three actions are performed pulling parts in virtual or system buffers, finding an appropriate buffer if the departing part is a transient part, and checking blocked parts for an available place by a part departure.

4.3 Simulation Design and System

A hypothetical job shop multi-cell FMS was selected for the experiment. The multi-cell FMS is depicted in Figure 3.

Simulation was used to compare the performance of the virtual model against the conventional model for different experimental conditions. The models were tested under the following experimental conditions: varying job mixes, different limits on the number of parts allowed in the system(LWIP), varying AGV fleet sizes and different buffer capacities. And the SPT(Shortest Processing Time) rule is selected as the machine scheduling rule. An idle machine selects a part in the cell input buffer that requires the shortest processing time in the machine.

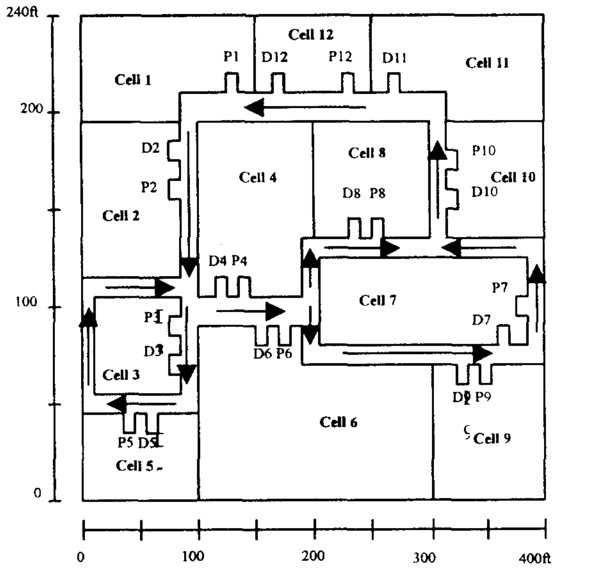

Figure 3. Job shop multi-cell FMS and guidepath layout

5. SIMULATION RESULTS

The simulation was developed using the SIMAN[8] general purpose simulation language and C programming language.

Two different measures were used to compare the performances of the virtual model against the conventional model for different experimental conditions. The measures of relative performance tested are: Throughput, Maximum number of parts in the system buffer(MNPS) at a moment during entire simulation duration for each experiment.

MNPS was selected to show the difference between models on the required capacity of the system buffer to have a deadlock free system.

5.1 Relative Performance of the Buffer Management Models at Varying Buffer Capacities, AGV Fleet Sizes and LWIPs

The effect of different buffer capacities, AGV fleet sizes and LWIPs on the relative performance of the buffer management models was investigated in this study. The throughput and MNPS performances of two buffer management models with job mix are summarized in Figure 4 and Figure 5.

Figure 4 illustrates the average throughputs of two models under different experimental conditions when job mix is used. For each model, the throughputs monotonically increase as the number of AGVs and/or the buffer capacities increase over the entire spectrum of experiments. Also as the LWIPs increase, the throughputs increase except in the cases of small numbers of AGVs with small buffer capacities for both models. Due to slow MHS(small buffer size) cannot keep up with the demand, consequently causing the throughput to decrease.

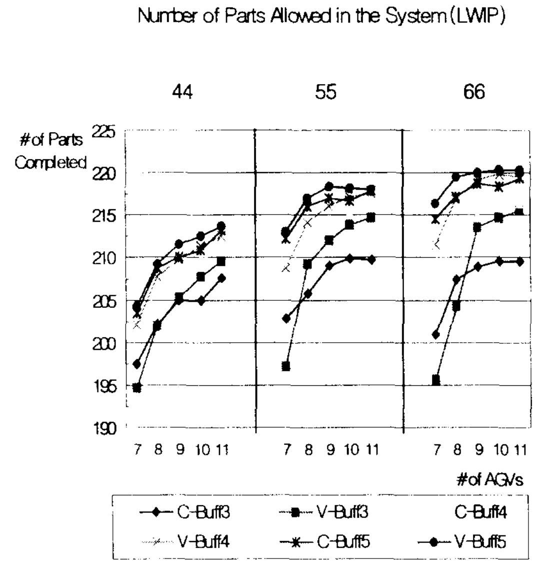

Figure 4. Throughput for job mix

Between the two models, the virtual model provided better throughputs than the conventional model in all cases except in the cases of small numbers of AGVs with a small buffer capacity. Also, as the LWIPs increase, the improvement of the virtual model over the conventional model also increases.

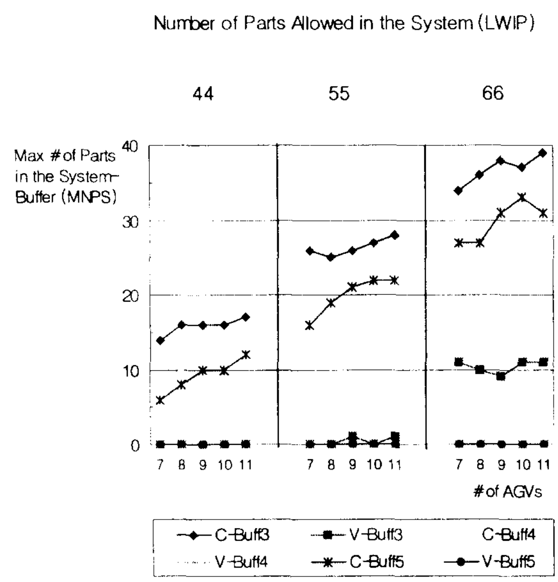

Figure 5. MNPS in the system buffer for job mix

Figure 5 clearly illustrates that the virtual model reduces the required capacity of the system buffer. When the buffer size was 4 or 5, there were no parts that visited the system buffer under the virtual model where as much as 38 parts at a moment were in the system buffer under the conventional model.

6. CONCLUSION AND RECOMMENDATION

A buffer management model(the virtual system buffer model) for random job shop FMSs with AGVs was presented in this paper. The virtual model uses some portion of each local buffer as a system buffer.

The simulation experiments conducted in this research clearly indicate that having a proper buffer management, suited for the system, could result in higher throughputs. The proposed buffer management model is superior over the conventional buffer management model in terms of throughputs and the required capacity of the system buffer.

Some considerable alternatives that might improve the virtual model are: Increasing the portion of each cell I/O buffer that can be used only by the parts for the cell; Giving the same priority to the parts in the system buffer with the parts in the virtual system buffer. It should reduce the possibility that a part in the system buffer stays extremely long period of time; Finally, since cell buffers do function as system buffers, system buffers are no longer needed unless it is cost effective. Instead, the capacity of cell buffers may be increased.

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